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GB-A- 2 112 930  
US-A- 3 899 213  
US-A- 4 433 245

ANALYTICAL CHEMISTRY, vol. 49, no. 8, July 1977, pages 1112-1120; H.L. FELKEL, Jr. et al.: "Design and evaluation of a random access vidicon-echelle spectrometer and application to multielement determinations by atomic absorption spectrometry"

ANALYTICAL CHEMISTRY, vol. 55, no. 8, July 1983, pages 836A-842A; S.A. BORMAN: "Photodiode array detectors for LC"

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## Descripti n

This invention relates to an airborne optical spectrometer system for detecting anomalies at or near the surface from the air.

The detection of anomalies in optical response at, above or below marine surfaces and at or above land surfaces can be of great value in identifying and locating phenomena due to materials such as pollutants and minerals. Incorporating optical equipment on an airborne platform for this task provides a rapid reconnaissance technique.

Minerals may be exposed by weathering to produce the anomalies or there may be a surface expression of subsurface materials.

A particularly important example of the latter is the natural seepage of hydrocarbons from subterranean reservoirs which may be either on or offshore.

Offshore petroleum exploration technology, especially the use of reflection seismic, has developed to the extent that the structure and thickness of potentially oil-bearing rocks can be determined with a degree of confidence which is limited mostly by cost. However, many areas still have either widely scattered wells or no wells at all, and in such places geochemical information may be insufficient to determine whether petroleum has been generated and its subsequent history.

In such circumstances there is a need for direct information about the occurrence of petroleum in the subsurface. Fortunately, the gas phase of petroleum is buoyant and has the capacity, demonstrated in several mature offshore production provinces, to breach trap seals and rise through the overburden to give flowing gassy seeps in the sea. Bubble plumes caused by gas seepage from oil-fields have been reported, for example, from the North Sea, the Gulf of Mexico and offshore Brunei. Some bubbles may contain oil or gas condensate in addition to natural gas and this liquid phase will form a slick on the surface. In rough water the oil may become emulsified in the surface layer.

British patent specification 1516281 discloses a method for determining the presence of hydrocarbon seeps in the sea comprising

- (a) traversing an area of the sea in a moving vehicle,
- (b) generating a beam of primary light radiation and directing said light beam towards the sea, said beam being of sufficient intensity and of such wavelength composition to produce secondary light radiation in sub-surface zones of the sea, said secondary radiation being located near the surface of the sea,
- (c) receiving secondary light radiation emanating from said zones,
- (d) determining the intensity of said received secondary light radiation,

- (e) observing the positions in said area wherein said secondary light radiation was received, and
- (f) repeating the aforesaid steps (a)-(e).

This method involves the use of fixed and predetermined optical band coverage with fixed and predetermined low spectral resolution in the UV to red wavelength (300-800 nanometres). GB-A-2 112 930 describes an apparatus and method for detecting an anomaly at or near a water or land surface from the spectral composition of light emitted from the surface in which the secondary light emitted from the surface is collected and analysed.

We have now devised an improved, high spectral resolution, airborne optical detector system for, but not limited to, the remote detection of radiation from UV to far red wavelengths, whose spectral resolution across the wavelength region is computer configurable and can be adjusted according to the application.

Thus, according to the present invention there is provided apparatus for detecting an anomaly at or near a water or land surface which apparatus comprises means for generating a beam, preferably a pulsed beam, of light radiation, preferably ultra-violet light, and directing the beam towards the surface, the beam being sufficiently intense and of such a spectral composition that the beam causes the anomaly, if present, to emit secondary light radiation, means for collecting the secondary light radiation, or means for collecting solar induced secondary light radiation, the spectral analysis means for analysing the spectrum of the secondary radiation, comprising a high resolution, multi-element digitising detector for detecting the secondary light radiation, having a plurality of channels across the spectrum of the emitted secondary radiation, the channels being software configurable and under the control of a digitally addressable computer-operated controller, the concentration of used channels across the plurality of channels being adjustable and increasable in the regions of the spectrum of greatest interest.

Suitable means for generating the beam of primary light radiation include a laser.

The laser radiation may be provided by a continuous-wave laser with constant intensity. The laser radiation may have an intensity which varies with time, for example modulated or pulsed laser radiation. The laser radiation may be provided by a modulated or chopped, continuous-wave laser. The intensity of the radiation may vary in the form of a sine wave or square wave or may be pulsed. The laser radiation may be provided by a pulsed laser, for example an ultra-violet excimer, a visible metal gas discharge laser, a flash lamp-pumped or a semi-conductor pumped solid-state laser. Such lasers may be Nd-YAG lasers, ruby lasers or pulsed argon ion lasers. The pulsed lasers may have

nanosecond or picosecond pulse widths. The picosecond pulsed lasers may comprise a source laser, a synchronously pumped, cavity dumped, dye laser with amplifiers and further wavelength shifting units. The lasers may have regenerative amplification systems with high repetition rate may be included in the picosecond source of laser radiation.

Suitable light collection means include an optical telescope.

Suitable spectral analysis means include a grating spectrograph.

Output from the detector will normally be logged and may be displayed and/or stored as desired.

When the application is for petroleum prospecting, the primary light is preferably generated by an ultra-violet excimer laser producing light of wavelength 308 nm and the detection system is capable of receiving secondary radiation from petroleum films or emulsions. The spectral region of interest covers the ultra violet light induced fluorescent emission in the wavelength range from 300 to 800 nm. The lower wavelength boundary is determined by the excimer laser operating preferably at 308 nm; this wavelength has been shown to be the most advantageous for excitation of petroleum aromatic components by virtue of their high absorption coefficients at 308 nm and high fluorescence quantum yield.

The detector may contain 512, 1024 or 2048 channels or more but only 90 may be required to provide adequate spectral coverage for the phenomenon of interest. The advantage in using the minimum number of channels to analyse the responses from the chosen phenomenon is that the data rates to be logged, and, therefore, the total signal acquired, can be kept to a minimum.

Specifically for this application the regions of interest are the water Raman signal, shifted 3000-3600 wavenumbers from the wavelength of the primary radiation and the rising edge of the oil fluorescence, whereas the long wavelength fluorescence need only be analysed to low spectral resolution.

Thus, the invention may be flexibly configured to provide high spectral resolution in the spectral regions of interest, i.e., from 300 nm to 500 nm, with much lower spectral resolution beyond. The non-used channels at any moment in time are redundant but when appropriate (for the appraisal of a different phenomenon) may be brought into operation by means of the digitally addressable, software configurable controller.

According to another aspect of the present invention there is provided a method for detecting an anomaly at or near a water or land surface by generating a beam, preferably a pulsed beam, of

primary light radiation, preferably ultra-violet light, and directing the beam towards the surface, the beam being sufficiently intense and of such spectral composition that the beam causes the anomaly, if present, to emit secondary light radiation, collecting the secondary light radiation, or collecting solar induced secondary radiation, detecting and analysing the spectrum of the secondary light radiation by means of a high resolution, multi-element digitising detector having a plurality of channels across the spectrum of the emitted secondary radiation, the channels being software configurable and under the control of a digitally addressable computer operated controller, the concentration of used channels across the plurality of channels being adjusted and increased in the region of the spectrum of greatest interest and decreased in the regions of least interest.

The invention is illustrated by but not limited with reference to the accompanying drawing which is a diagrammatic representation of an airborne laser fluorosensing system.

The system is fitted within the interior of a light aircraft 1. It comprises an excimer laser 2 emitting a pulsed beam 3 of primary ultra-violet light radiation which is reflected by a mirror 4 through a port 5 in the underside of the aircraft and directed downwardly to the surface of the sea 6.

Rays of secondary light radiation 7 induced by the primary beam are collected by a reflecting telescope 8, further reflected by the mirror 4 and passed through a grating spectrograph 9 which disperses the light onto a gateable, intensified optical multi-channel detector 10 which is software configurable and capable of multi-element digitising.

As an example, the spectral region given 310 nanometres to 360 nanometres may be configured to have a spectral resolution of one channel per nanometre, and the spectral region from 361 nanometres to 500 nanometres may be configured to have a spectral resolution of one channel for every four nanometres and the resolution beyond 500 nanometres may be configured to be one channel for every eight nanometres. The variable channel digitization is illustrated by Figure 2. The remaining channels are redundant for this particular use, but channels may be brought into and out of use as and when required.

From the detector, signals are passed to a digitally addressable software configurable controller 11 which controls the effective digitisation across multi-element detector.

Data is logged, displayed and stored by logger 12, display unit 13 and store 14.

## Claims

1. Apparatus for detecting an anomaly at or near a water or land surface which apparatus comprises means (2) for generating a beam of primary light radiation, and directing the beam towards the surface, the beam being sufficiently intense and of such a spectral composition that the beam causes the anomaly, if present, to emit secondary light radiation, means (8) for collecting the secondary light radiation, or means for collecting solar induced secondary light radiation, and spectral analysis means (9) for analysing the spectrum of the secondary radiation, characterised by the fact that the spectral analysis means for analysing comprises a high resolution, multi-element digitising detector (10) for detecting the secondary light radiation, having a plurality of channels across the spectrum of the emitted secondary radiation, the channels being software configurable and under the control of a digitally addressable computer-operated controller (11), the concentration of used channels across the plurality of channels being adjustable and increasable in the regions of the spectrum of greatest interest and decreasable in the regions of least interest. 5
2. Apparatus according to claim 1 wherein the means (2) for generating the beam of primary light radiation is a laser. 10
3. Apparatus according to claim 2 wherein the laser (2) is a pulsed laser. 15
4. Apparatus according to any of the preceding claims wherein the means (2) for generating the primary light radiation is means for generating ultra-violet light. 20
5. Apparatus according to claim 4 wherein the means (2) for generating ultra-violet light is an excimer laser. 25
6. Apparatus according to any of the preceding claims wherein the means (8) for collecting the secondary light radiation is an optical telescope. 30
7. Apparatus according to any of the preceding claims wherein the spectral analysis means (9) is a grating spectroph. 35
8. Apparatus according to any of claims 4 to 7 wherein the means (2) for generating a pulsed beam of ultra-violet light is capable of generating light of wavelength 308 nm. 40
9. Apparatus according to any of the preceding claims wherein the detector (10) is capable of detecting light in the wavelength range of 300 to 800 nm. 45
10. Apparatus according to claim 9 wherein the apparatus is capable of providing relatively high adjustable spectral resolution in the wavelength region up to 500 nanometres and relatively low spectral resolution for the wavelength beyond 500 nanometres. 50
11. A method for detecting an anomaly at or near a water or land surface by generating a beam of primary light radiation, and directing the beam towards the surface, the beam being sufficiently intense and of such spectral composition that the beam causes the anomaly, if present, to emit secondary light radiation, collecting the secondary light radiation, or collecting solar induced secondary radiation, and analysing the spectrum of the secondary radiation characterised by the fact that the secondary light radiation is detected and analysed by means of a high resolution, multi-element digitising detector having a plurality of channels across the spectrum of the emitted secondary radiation, the channels being software configurable and under the control of a digitally addressable computer operated controller, the concentration of used channels across the plurality of channels being adjusted and increased in the region of the spectrum of greatest interest and decreased in the regions of least interest. 55

## Patentansprüche

1. Vorrichtung zum Entdecken einer Anomalität auf oder in der Nähe einer Wasser- oder Landoberfläche, die Mittel (2) zur Erzeugung eines Strahles einer Primärlichtstrahlung und zum Richten dieses Strahles gegen die Oberfläche aufweist, wobei der Strahl ausreichend intensiv und von einer solchen spektralen Zusammensetzung ist, daß der Strahl die Anomalität, falls sie vorhanden ist, dazu veranlaßt, eine Sekundärstrahlung abzugeben, mit Mitteln (8), um die Sekundärlichtstrahlung zu sammeln oder mit Mitteln, um eine solarinduzierte Sekundärlichtstrahlung zu sammeln und mit Mitteln (9) für eine Spektralanalyse zum Analysieren des Spektrums der Sekundärstrahlung, dadurch gekennzeichnet, daß die Mittel zur Spektralanalyse für die Analyse aus einem vielzelligen digitalisierenden Detektor (10) mit hoher Auflösung zum Detektieren der Sekundärlichtstrahlung bestehen, die eine Vielzahl von Kanälen

- quer durch das Spektrum der abgegebenen Sekundärstrahlung besitzt, die als Software abbildbar sind und unter der Kontrolle eines digital adressierbaren von einem Rechner betriebenen Regler (11) stehen, wobei die Konzentration der benutzten Kanäle über die Mehrzahl der Kanäle justierbar und in den Bereichen des Spektrums, die am meisten interessant sind, erhöhbar und in den Bereichen des geringsten Interesses erniedrigbar sind.
2. Vorrichtung nach Anspruch 1, bei der die Mittel (2) zur Erzeugung des Strahles der Primärlichtstrahlung ein Laser sind.
  3. Vorrichtung nach Anspruch 2, bei der der Laser (2) ein gepulster Laser ist.
  4. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der die Mittel (2) zur Erzeugung der Primärlichtstrahlung Mittel zur Erzeugung ultravioletten Lichtes sind.
  5. Vorrichtung nach Anspruch 4, bei der die Mittel (2) zur Erzeugung von ultraviolettem Licht ein Excimerlaser sind.
  6. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der die Mittel (8) zum Sammeln der Sekundärlichtstrahlung als ein optisches Teleskop ausgebildet sind.
  7. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der die Mittel zur Spektralanalyse ein Gitterspektrograph sind.
  8. Vorrichtung nach einem der Ansprüche 4 bis 7, bei der die Mittel (2) zur Erzeugung eines gepulsten Strahles ultravioletten Lichtes geeignet sind, Licht mit einer Wellenlänge von 308 nm zu erzeugen.
  9. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der der Detektor (10) geeignet ist, Licht mit Wellenlängen in der Größenordnung von 300 bis 800 nm zu entdecken.
  10. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß sie geeignet ist, im Wellenlängenbereich bis zu 500 Nanometern eine relativ hoch einstellbare Spektralauflösung und für Wellenlängen über 500 Nanometer eine relativ niedrige Spektralauflösung vorzusehen.
  11. Verfahren zum Entdecken einer Anomalität auf oder in der Nähe einer Wasser- oder Landoberfläche durch Erzeugen eines Strahles einer Primärlichtstrahlung und Richten dieses

Strahles auf die Oberfläche, wobei der Strahl ausreichend intensiv und von einer Spektralzusammensetzung ist, daß der Strahl die Anomalität, falls sie vorhanden ist, dazu veranlaßt, eine Sekundärlichtstrahlung auszusenden, Sammeln der Sekundärlichtstrahlung oder Sammeln einer solarinduzierten Sekundärstrahlung und Analysieren des Spektrums der Sekundärstrahlung, dadurch gekennzeichnet, daß die Sekundärlichtstrahlung mit Hilfe eines hoch auflösenden vielzelligen digitalisierenden Detektors entdeckt und analysiert wird, der eine Vielzahl von Kanälen über das Spektrum der ausgesandten Sekundärstrahlung aufweist, die als Software abbildbar und unter der Kontrolle eines digital adressierbaren rechnergesteuerten Reglers stehen, wobei die Konzentration der benutzten Kanäle über die Vielzahl der Kanäle einjustierbar ist und in dem Bereich des Spektrums, das das meiste Interesse hat, erhöhbar und in den Bereichen des geringsten Interesses erniedrigbar ist.

#### Revendications

1. Appareil destiné à détecter une anomalie sur ou près d'une surface d'eau ou de terre, ledit appareil comprend un moyen (2) destiné à générer un faisceau de rayonnement premier ou primaire de lumière et à diriger le faisceau vers la surface, le faisceau étant suffisamment intense et de composition spectrale suffisante pour que le faisceau oblige l'anomalie, le cas échéant, à émettre un rayonnement de lumière secondaire, des moyens (8) destinés à collecter le rayonnement de lumière secondaire, ou des moyens destinés à collecter un rayonnement de lumière secondaire induit par le soleil, et des moyens d'analyse spectrale (9) destinés à analyser le spectre du rayonnement de lumière ou lumineux secondaire, caractérisé par le fait que les moyens d'analyse du spectre destinés à analyser comprennent un détecteur (10) de numérisation multicellulaire à haute résolution destiné à détecter le rayonnement de lumière secondaire, présentant plusieurs canaux à travers le spectre de rayonnement secondaire émis, les canaux pouvant être configurés avec un logiciel et commandés par un mécanisme de commande (11) actionné par ordinateur adressable de manière numérique, la concentration de canaux utilisés à travers les divers canaux pouvant être ajustée et augmentée dans les zones du spectre d'intérêt supérieur et diminuée dans les zones d'intérêt moindre.

2. Appareil selon la revendication 1, dans lequel le moyen (2) destiné à générer le faisceau de rayonnement premier de lumière est un laser.
3. Appareil selon la revendication 2, dans lequel le laser (2) est un laser impulsif. 5
4. Appareil selon l'une des revendications précédentes, dans lequel le moyen (2) destiné à générer le rayonnement premier de lumière est un moyen destiné à générer une lumière ultra-violette. 10
5. Appareil selon la revendication 4, dans lequel le moyen (2) destiné à générer la lumière ultra-violette est un laser excimer. 15
6. Appareil selon l'une des revendications précédentes, dans lequel le moyen (8) destiné à collecter le rayonnement lumineux secondaire est un télescope optique. 20
7. Appareil selon l'une des revendications précédentes, dans lequel les moyens d'analyse spectrale (9) sont un spectographe à diffraction. 25
8. Appareil selon l'une des revendications 4 à 7, dans lequel le moyen (2) destiné à générer un faisceau impulsif de lumière ultra-violette peut générer une lumière d'une longueur d'onde de 308 nm. 30
9. Appareil selon l'une des revendications précédentes, dans lequel le détecteur (10) peut détecter une lumière comprise dans la gamme de longueurs d'onde allant de 300 à 800 nm. 35
10. Appareil selon la revendication 9, dans lequel l'appareil peut fournir une résolution spectrale ajustable relativement haute dans la zone de longueur d'onde allant jusqu'à 500 nanomètres et une résolution spectrale relativement faible pour la longueur d'onde inférieure à 500 nanomètres. 40  
45
11. Méthode destinée à détecter une anomalie sur ou près d'une surface d'eau ou de terre en générant un faisceau de rayonnement premier lumineux ou de lumière et à diriger le faisceau vers la surface, le faisceau étant suffisamment intense et de composition spectrale suffisante pour que le faisceau oblige l'anomalie, le cas échéant, à émettre un rayonnement de lumière secondaire, à collecter le rayonnement de lumière secondaire, ou à collecter le rayonnement secondaire induit par le soleil, et à analyser le spectre du rayonnement secondaire, ca- 50  
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ractérisé par le fait que le rayonnement de lumière secondaire est détecté et analysé au moyen d'un détecteur de numérisation multicellulaire à haute résolution présentant plusieurs canaux à travers le spectre du rayonnement secondaire émis, les canaux pouvant être configurés avec un logiciel et commandés par un mécanisme de commande actionné par ordinateur adressable de manière numérique, la concentration de canaux utilisés étant ajustée et augmentée dans la zone du spectre d'intérêt supérieur et diminuée dans les zones d'intérêt moindre.

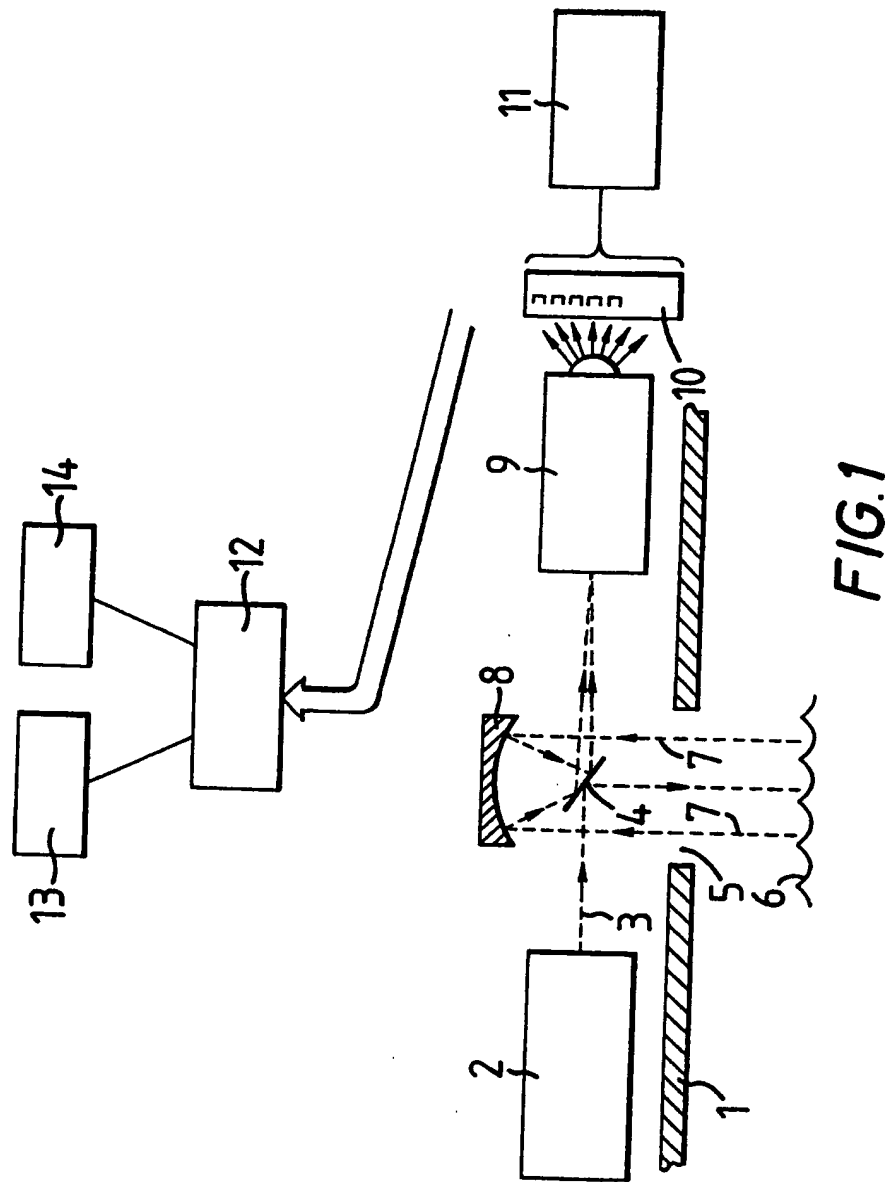


FIG.1

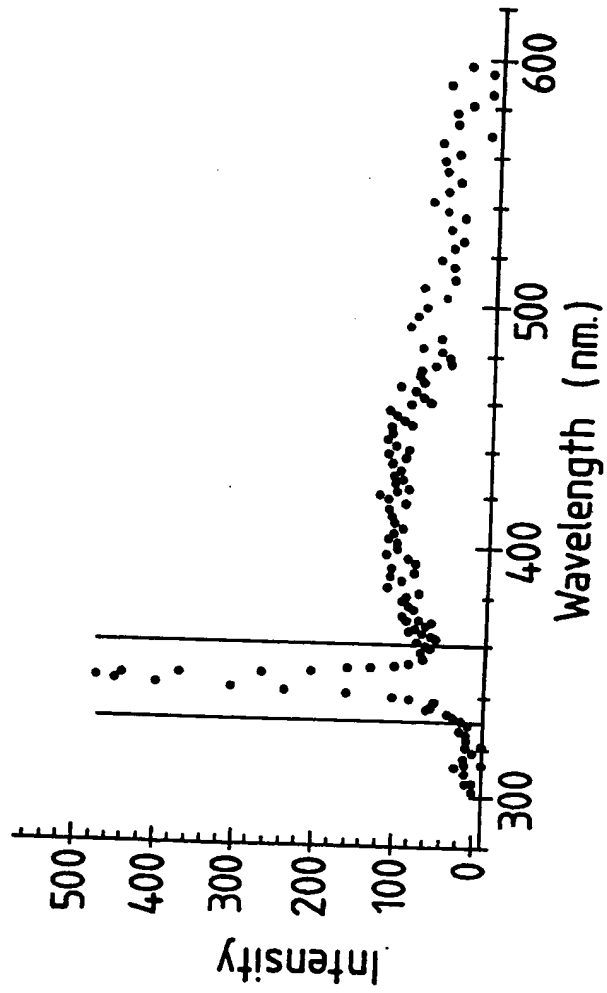


FIG. 2